SID 66-957-1

SCIENTIFIC MISSION SUPPORT FOR EXTENDED LUNAR EXPLORATION

Final Report

Volume 1

Condensed Summary

December 1966

NORTH AMERICAN AVIATION, INC.
SPACE and INFORMATION SYSTEMS DIVISION

FOREWORD

This document contains the Condensed Summary Report concerning the results of a study of Scientific Mission Support for Extended Lunar Exploration. This study was performed by the Space and Information Systems Division of North American Aviation, Incorporated, for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration under Contract No. NAS8-20258.

The study was performed under the technical direction of Dr. N. C. Costes of the Research Projects Laboratory of NASA-MSFC, during a 7-1/2 month period beginning in 13 December 1965. The general guidelines of the study were stipulated in DCN 1-5-21-00019 (1F).

The complete results of the study are presented in the following volumes

Volume 1 - Condensed Summary Report

Volume 2 - Task Summary Report

Volume 3 - Detailed Technical Report

Volume 4 - Appendix A - Experiment Sequences - Computer Printouts

Volume 5 - Appendix B - Master Data Report - Computer Printouts

Volume 6 - Appendix C - Computer Program

CONTENTS

ILLUSTRATIONS

TABLES

1.0 INTRODUCTION

This report presents the results of a study conducted to define the support requirements for scientific missions in extended lunar exploration. The study considers the probable extent of scientific investigations to be accomplished in extended lunar exploration. It develops an estimate of associated technology investigations, experimental systems and operational requirements; and presents the results within the format of a data management system which facilitates application and continuing utility in mission planning.

As the Apollo program progresses toward the first manned lunar landing, urgency is placed on planning for manned lunar exploration. This planning represents a significant portion of the overall planning for the manned exploration of space, which is a major responsibility of NASA.

The study of scientific missions and their associated support requirements is directly in support of NASA's planning for manned lunar exploration missions and systems. Utility in support of lunar mission planning is facilitated by consideration of all exploration phases with major emphasis on extended phases and by the absence of constraints associated with candidate systems. Both lunar surface and orbital scientific missions directly related to extended lunar exploration are included. Effectiveness is improved additionally by the inclusion of supporting technology and research investigations associated with lunar scientific missions. An enhancement of value having a different order is indicated where the lunar exploration program serves as a space science and technology base for manned planetary exploration missions and systems.

The Scientific Mission Support for Extended Lunar Exploration study was performed between December 1965 and August 1966. It is a second-generation study that builds on the results of previous studies. It was guided by and incorporated data obtained from preceding space science conferences and other NASA-supplied documentation. The results are to be used as input data to other NASA contracts and studies. Relationships to other NASA activities are described in more detail in Section 3.0 of this volume.

The purposes of a long-term lunar exploration program include the acquisition of information from the Moon to determine its environment, composition, and gross body properties and modification processes. A distinctly different purpose is to utilize the unique characterisitics of the Moon to establish observatories and laboratories for long-term scientific investigations. It is also desirable to determine if lunar resources could be used for extended lunar operations, future interplanetary exploration, and terrestrial purposes.

Early lunar exploration objectives were formulated by the working groups of the NASA 1965 Summer Conference on Lunar Exploration and Science which took place at Falmouth, Massachusetts (Reference 1). Parallel with this activity, the Space Sciences Board of the National Academy of Sciences, during its 1965 summer meeting at Woods Hole, Massachusetts, formulated scientific objectives for future space research which appear in the report, "Space Research—Directions for the Future" (Reference 2). In that document, scientific objectives relating to the exploration of the Moon are delineated in the form of 15 specific fundamental questions. Scientific objectives relating to space-oriented investigations which can be performed from the Moon can also be inferred from the same document and can be expressed in the form of 18 additional fundamental questions. (See Volume III, "Detailed Technical Report.") Both of these sources provided the basic scientific guidelines for the compilation of experiments under this contract effort.

The scope of the study encompasses the following general study areas:

1. Compilation of fundamental experiments* and investigations** from NASA-supplied source material
2. Generation of mission support, and basic and applied research investigations
3. Development of an experiment data management system based on digital computer utilization, and computer program documentation for use by NASA
4. Description of investigations/experiments and of support requirements in encoded format, and entry into the data management system
5. Organization of investigations/experiments into four separate types of sequences for application to scientific mission planning
6. Assessment of implications of scientific mission support requirements to mission systems and subsystems to include astronaut suited capabilities, surface mobility, and major fixed-site scientific facilities
7. A summary review of exploration program factors, and estimation of the requirements for Earth-based scientific support

Results of the study are summarized in Section 5.0 of this volume.

---

*An Experiment is defined as a series of measurements or observations intended to yield specific information required to accomplish part of an investigation. An experiment may have one or more replications. Example: (1) measurement of material density; (2) observation of petrologic character, e.g., crystalline, amorphous, sedimentary, igneous, metamorphic, etc.

**An Investigation is defined as an exercise involving a group of closely related experiments performed concurrently and/or sequentially with the intent of acquiring a specified amount of a particular kind of information within a technical area. Example: (1) determination of the number and relative amounts of different minerals in a given area; (2) photographic survey of the lunar equatorial region with a specified degree of optical resolution. An investigation can consist of one experiment only. In this case, the terms "experiment" and "investigation" are synonymous.

2.0 STUDY OBJECTIVE

The basic objective of this study is to provide an integrated estimate of experimental systems and operational support requirements for typical lunar scientific missions or programs. As a part of the basic objective, timely definition of extended scientific mission requirements is desired to most effectively influence the definition of future lunar exploration systems starting with the Apollo Applications Program missions.

A supporting objective is to develop and implement an experiment data management system suitable for use as a technical and management tool for application to future lunar scientific mission and mission support planning. Flexibility and expandability are desired in order to meet NASA's evolving data management needs in this area.

3.0 RELATIONSHIP TO OTHER NASA ACTIVITIES

The study of Scientific Mission Support for Extended Lunar Exploration is one of a family of studies performed by industry and by groups representing the scientific community in support of NASA's program of lunar exploration planning. Study areas generically are: scientific, technological, and systems. Past studies have emphasized the scientific and exploration systems requirements, concepts, and trade-off—research and technology being considered within the context of these activities.

This study is a second-generation scientific mission support study. It incorporates, in part, the results of previous studies and derives guidance with regard to lunar scientific mission objectives, and obtains suggested investigations and experiments from the results of the two 1965 summer studies (References 1 and 2). Scientific mission data from the study "Mission Modes and Systems Analysis for Lunar Exploration (MIMOSA)" (Reference 4) are also incorporated into this study. Through a major package of source material supplied by NASA and consisting of 90 documents, this study builds upon numerous past activities which contribute to lunar exploration planning.

The results of this study provide information to be used for the MIMOSA effort along with other studies being performed under separate NASA contracts. The organized compilation of investigations and experiments in the form of a computer card deck and associated computer program documentation will be kept up to date and used internally by NASA. Study results will be applied to future lunar science and technology and mission studies. Relation to planetary exploration is also potentially significant.

4.0 GUIDELINES AND STUDY APPROACH

Guidelines initially provided and extended by NASA were utilized in organizing and performing the study. In summary form, these guidelines were:

1. Scientific guidelines should be derived from the report of a study conducted by the Space Science Board entitled "Space Research—Directions for the Future" and from the report of the NASA 1965 Summer Conference on Lunar Exploration and Science (References 1 and 2). Fundamental experiments (see Section 5.2) should be compiled from References 1 and 2 and other NASA source documentation.

2. Use should be made of the results of previous scientific mission support studies relating to single-point candidate systems for extended lunar exploration that are pertinent to the expanded scope of this study.

3. Scientific mission definition should not be tailored to constraints imposed by a specified transportation mode for a particular time period, nor should they be restricted to missions associated with specific lunar base candidate systems.

4. Some understanding of the practical limits and general utility of the proposed AAP effort should be acquired in order to assess the extent that the early effort of lunar exploration can influence the later phases of the program.

5. An assessment of the penalty to the scientific effort by the lack of adequate personnel mobility should be made.

6. A reasonable effort should be made to understand, and factor into the study, the relationship between scientific exploration growth and the possible growth patterns and development modes that will comprise the personnel and logistics transportation and the lunar base system capability.

7. The study results should serve as an input to the concurrent Mission Modes and System Analysis Study (Reference 4).

To facilitate the exchange of information between groups conducting this study and the MIMOSA Study, the effort was organized into two phases. Phase 1 included the compilation of experiments and supporting requirements and the development of an experiment data management system. Phase 2 was concerned primarily with the development of experiment sequences, evolutionary scientific programs, special system/subsystem considerations, exploration program factors, and Earth support requirements.

During the initial phase of the program, several source documents were screened for identification of potential experiments. Typical source documents consisted of contractor NASA reports, conference proceedings, scientific subgroup meetings, and NASA in-house study reports. The NASA-supplied objectives and guidelines including the reports of the two 1965 summer studies conducted at Falmouth and Woods Hole, Mass., (References 1 and 2) were used to guide screening and integration.

The initial review of source documents and guidelines supplied the scientific goals for lunar exploration and supported identification of specific objectives for each scientific discipline area. From the source documents, an initial listing of approximately 660 potential fundamental experiments was compiled. Subsequent effort removed duplicated or redundant experiments, combined overlapping experiments, defined investigations, and organized experiments into appropriate investigation areas.

The source documents also provided the basic data for experiment descriptions, operational support requirements, parameter and equipment definition, and preliminary developmental characteristics.

Mission Support, and Miscellaneous Basic and Applied Research investigations were primarily derived by North American Aviation (NAA.) Source documents did identify some investigations, particularly in the applied biomedical and human factors, and life support discipline areas. Other investigations were identified by participating scientists and by technical participants; some were contributed by NASA.

The experiments and investigations, arranged by discipline area, were submitted to NASA for analysis and review by NASA and selected scientific and engineering groups. The results and comments of this review were then factored into the final data.

Formulation of the experiment data management system was initiated early in the study to provide a system for organizing, storing, and then rapidly retrieving, and handling the resulting screened data. The system was designed around the use of a digital computer for data storage and retrieval. Implementation of the data management system included (1) a review of the types of scientific experiments to be included, (2) selection of the experiment detail information categories, (3) selection of suitable input formats for computer handling of the data, (4) design of computer output formats for display of individual experiment and combined experiment summary information, (5) design of a computer program that would process the data inputs into the desired outputs, (6) compilation into the chosen format of the selected experiment information, (7) operation of the computer program, and (8) review and utilization of the summation capabilities to aid in analysis of support requirements of basic experiment groupings.

To provide logical order and grouping of experiments for utilization in mission analysis and planning, sequences were developed during Phase 2 of the study. The fundamental experiments were cataloged by:

1. Discipline Sequences within a particular scientific discipline in terms of a logical sequence of accomplishment to allow an orderly progression of scientific knowledge

2. Mission Support Sequences within a particular scientific discipline and across scientific disciplines in terms of increasing mission support parameters

3. Exploration Phase Sequences within a particular scientific discipline to identify logical phases of lunar exploration

4. Composite Sequences across scientific disciplines within a given exploration phase to aid in the delineation of an evolutionary program of lunar exploration and utilization and to indicate the relationship of interdisciplinary investigations with respect to support requirements.

During Phase 2, a brief study was performed of system and subsystem requirements and implications associated with the scientific experiments. Astronaut capabilities and limitations associated with transport (walking) and work task performance in the reduced traction, suited environment of the Moon were reviewed, based on data available in the literature. Mobility requirements from the experiment compilation were defined and assessed. Both extended surface mobility and local mobility support requirements were reviewed and the local mobility support requirements were correlated with astronaut suited capabilities. Configuration, performance, packaging, and deployment were examined for two potential scientific facilities selected as illustrative support requirements of lunar astronomy during extended exploration. These facilities included a long-wave radio telescope candidate system and a previous concept for a 100-inch lunar telescope system.

Other tasks accomplished during Phase 2 were concerned with program factors, including relation to planetary exploration and consideration of contingencies. Analyses of Earth-support scientific requirements, emphasizing the requirements for analysis of returned data, were also performed during Phase 2.

5.0 BASIC DATA GENERATED AND SIGNIFICANT RESULTS

5.1 EXPERIMENT COMPILATION SUMMARY

Three categories of investigations were identified in this study: Fundamental Investigations which were incorporated into the data management system organization within the eight discipline areas (0 through 7), shown in Table 1; Mission Support Investigations designated as Discipline Area 8; and Miscellaneous Basic and Applied Research, incorporated as Discipline Area 9.

Table 1 presents the distribution of experiments by discipline area. Subdivisions of lunar surface-based experiments into early (Apollo and Apollo Applications Program) and extended (post-Apollo Applications Program) phases, and numerical distribution of lunar orbital-based experiments are shown. Experiments suggested for performance in both early and extended phases are listed in the early phase. Orbital experiments are shown as part of the early and extended exploration missions.

Table 1. Experiment Summary

	Discipline Area	Early Exploration	Extended Exploration	Orbital	Totals
0	Lunar Atmospheres	4	2	0	6
1	Geodesy	5	0	2	7
2	Geology	9	3	2	14
3	Geochemistry	10	9	4	23
4	Geophysics	50	34	10	94
5	Particles and Fields	15	29	3	47
6	Biology	4	3	0	7
7	Astronomy	17	17	3	37
	Subtotal	114	97	24	235
8	Mission Support Invest.	60	30	6	96
9	Miscellaneous Basic and Applied Research	2	7	0	9
	Total	176	134	30	340

Figure 1 identifies the 10 discipline areas and illustrates in a matrix form the relationship between the investigations within each discipline area and the 33 fundamental questions. The relationship indicated by the key is qualitative. The entries do not indicate that the fundamental questions are fully answered; rather they indicate only the extent to which each investigation contributes to answering each fundamental question.

5.2 FUNDAMENTAL INVESTIGATIONS

The objective of this effort was to compile a typical spectrum of fundamental investigations and experiments that are postulated for the lunar exploration program.

Fundamental Investigations are those that will provide scientific data to aid in answering fundamental questions concerning the history and origin, enviroment, and properties of the Moon, the planets, and the universe. These activities are (1) lunar-oriented, or (2) conducted utilizing the Moon as a base. Studies of the planets also include those studies of the Earth that can be performed advantageously from the extraterrestrial vantage point of the Moon.

Identification of scientific discipline area objectives from guidelines and source material was an early output of the study. These objectives initially guided the experiment collation. In the future, these objectives will have continued use in cataloging and in formulating sequences of experiments.

As shown in Table 1, 235 distinct fundamental experiments were compiled from the NASA-supplied source material. These experiments, described and compiled in the data management system format, represent the major output of the experiments activity. A more detailed description of the experiments, including summary text and numerical data, is presented in Appendix B of the Detailed Technical Report, SID 66-957-5. The complete data package is designed for utility and flexibility of application to systems analysis and mission planning activities. The experiment text descriptions and experiment tabulation which presents key data in conventional decoded format is also included in the Detailed Technical Report, Volume 3, SID 66-957-3.

Definition of experiment support requirements for inclusion in the Fundamental Investigations compilation was a significant contribution to this activity. Operational support requirements, described for each experiment, represent an important part of the experiment support. Data fields included experiment location constraints, mobility requirements, number of men required, crew skill, and scientific man-hours. Because of the criticality of astronaut time, man-hour estimates considered base and traverse distribution, shirtsleeve and spacesuit conditions, and other conditions for a total of 16 data fields. Definition of scientific equipment included requirements, related characteristics, and preliminary developmental data. In addition to the direct compilation, this activity produced an alphabetical and commonality summary of major scientific equipment to facilitate future integration of basic data into mission formats. Preliminary estimates of telemetry requirements were also generated. A total of 85 data fields was included in the experiment compilation.

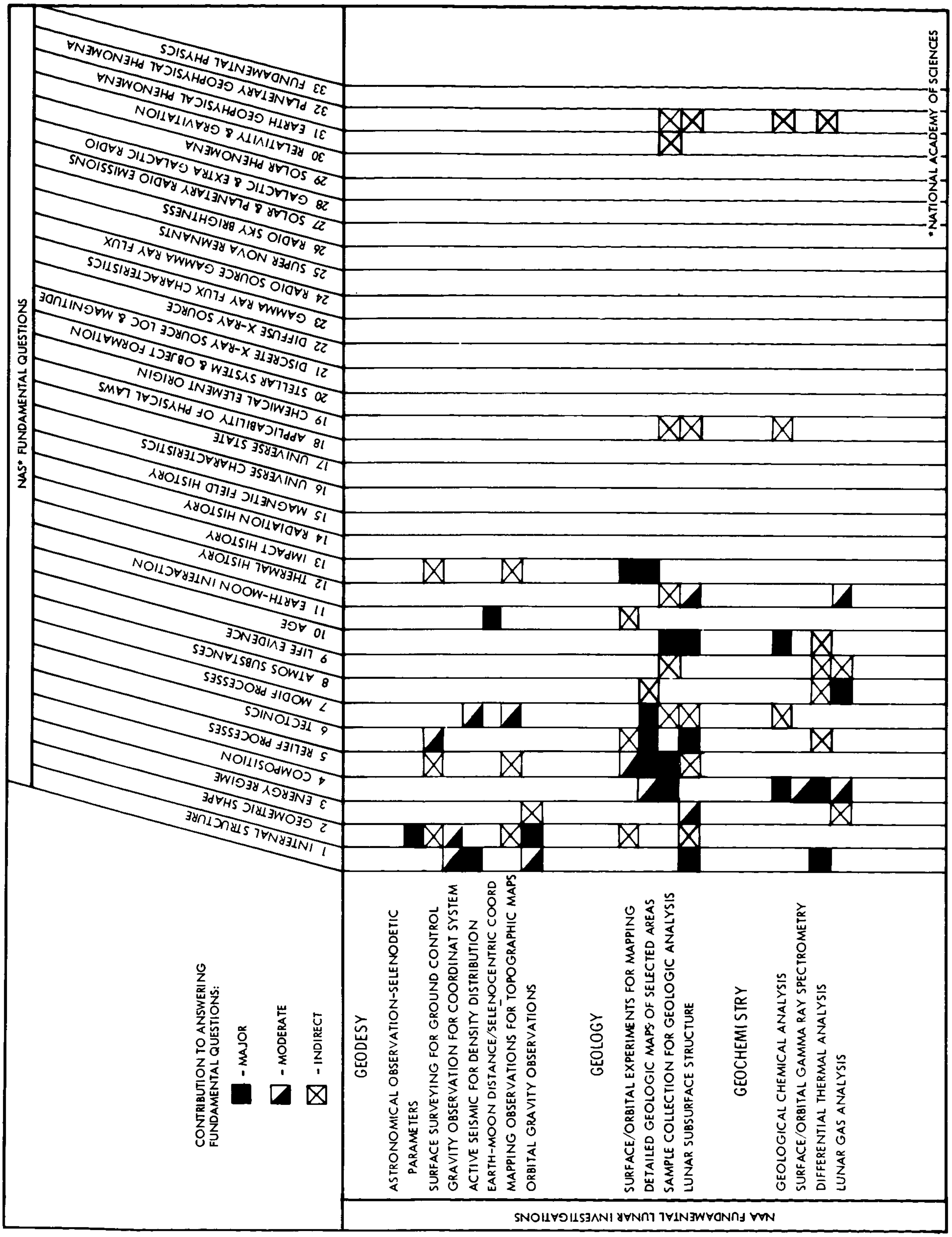

Figure 1a. Correlation of Fundamental Investigations With Fundamental Questions Raised by Space Science Board, National Academy of Sciences

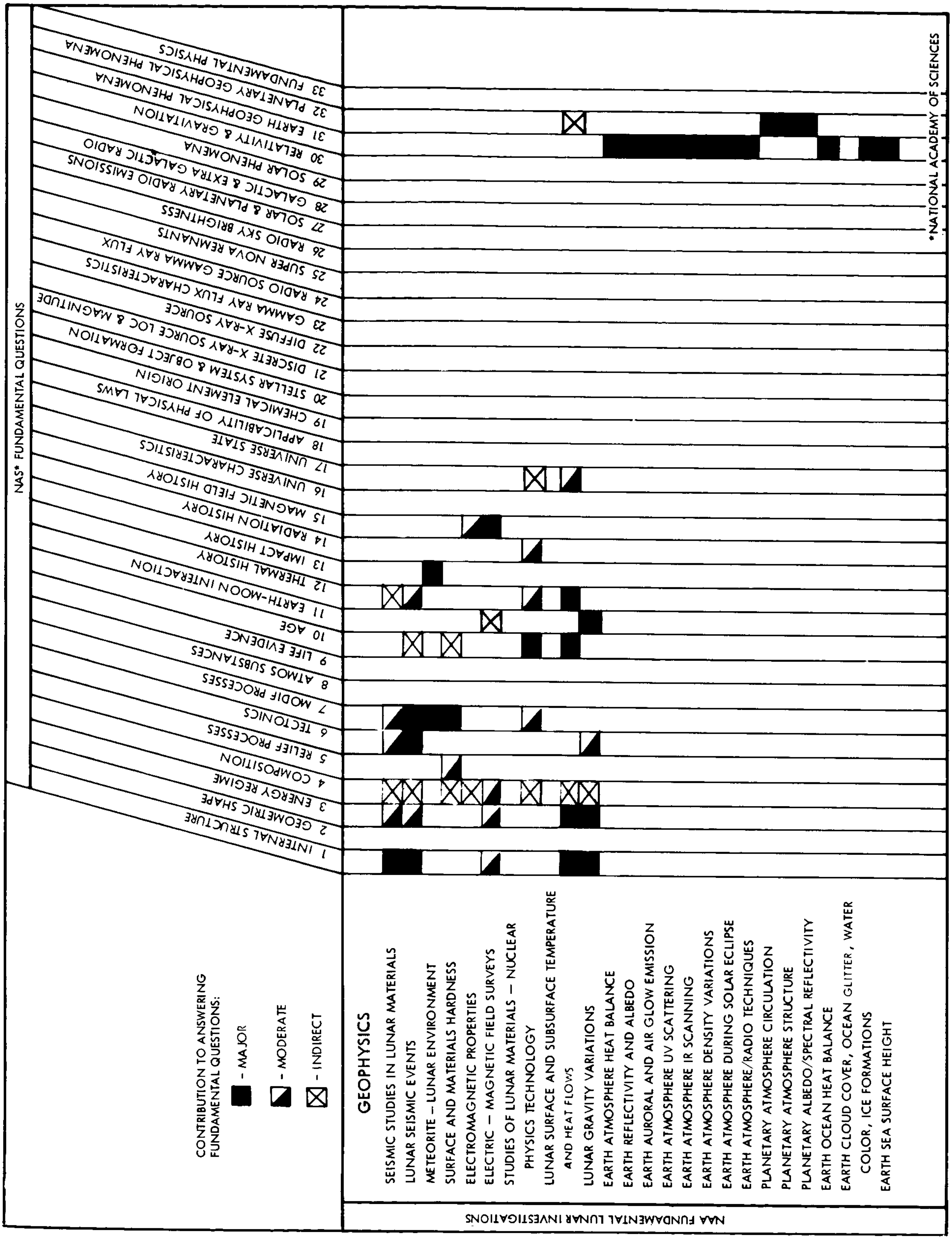

Figure 1b. Correlation of Fundamental Investigations With Fundamental Questions Raised by Space Science Board, National Academy of Sciences

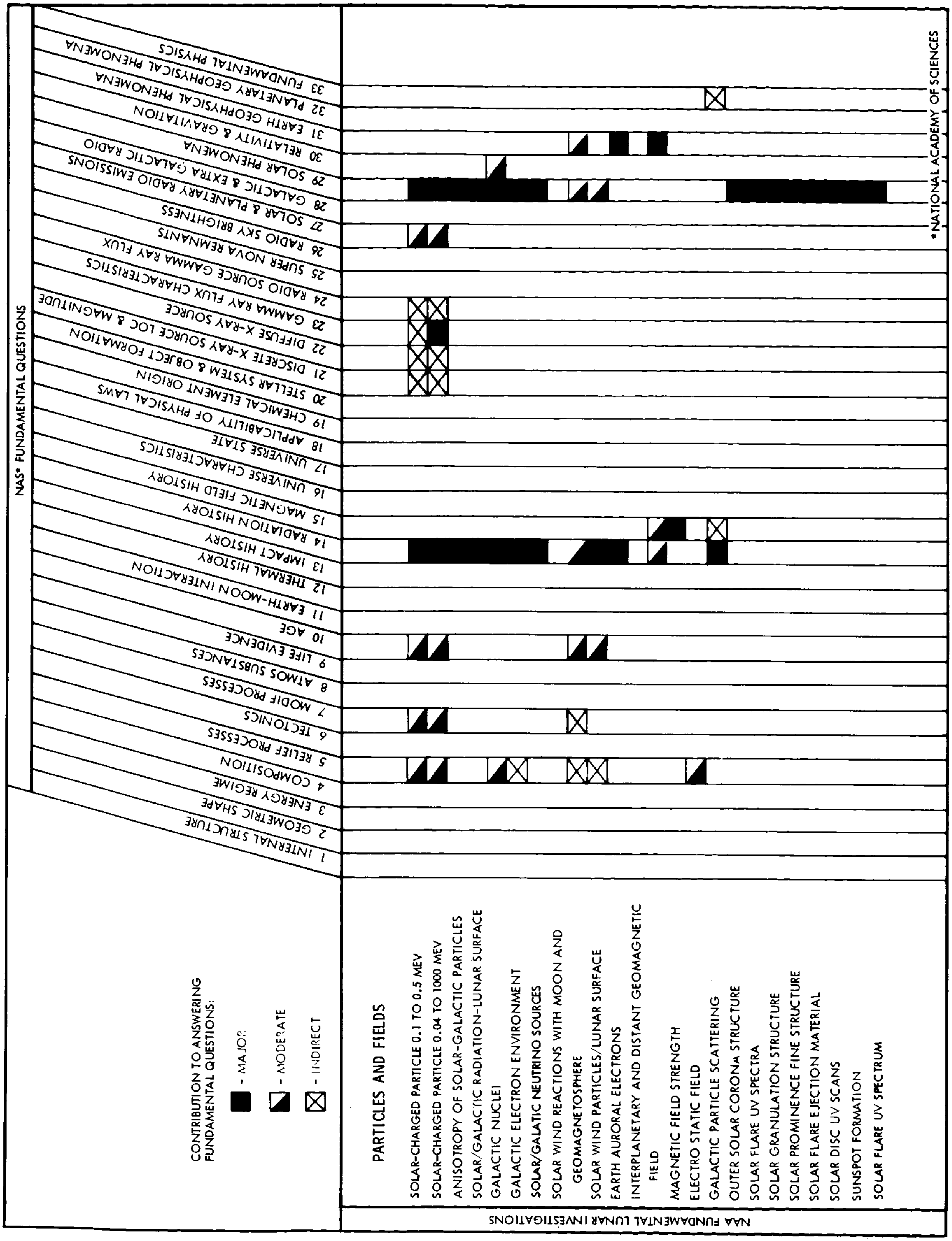

Figure 1c. Correlation of Fundamental Investigations With Fundamental Questions Raised by Space Science Board, National Academy of Sciences

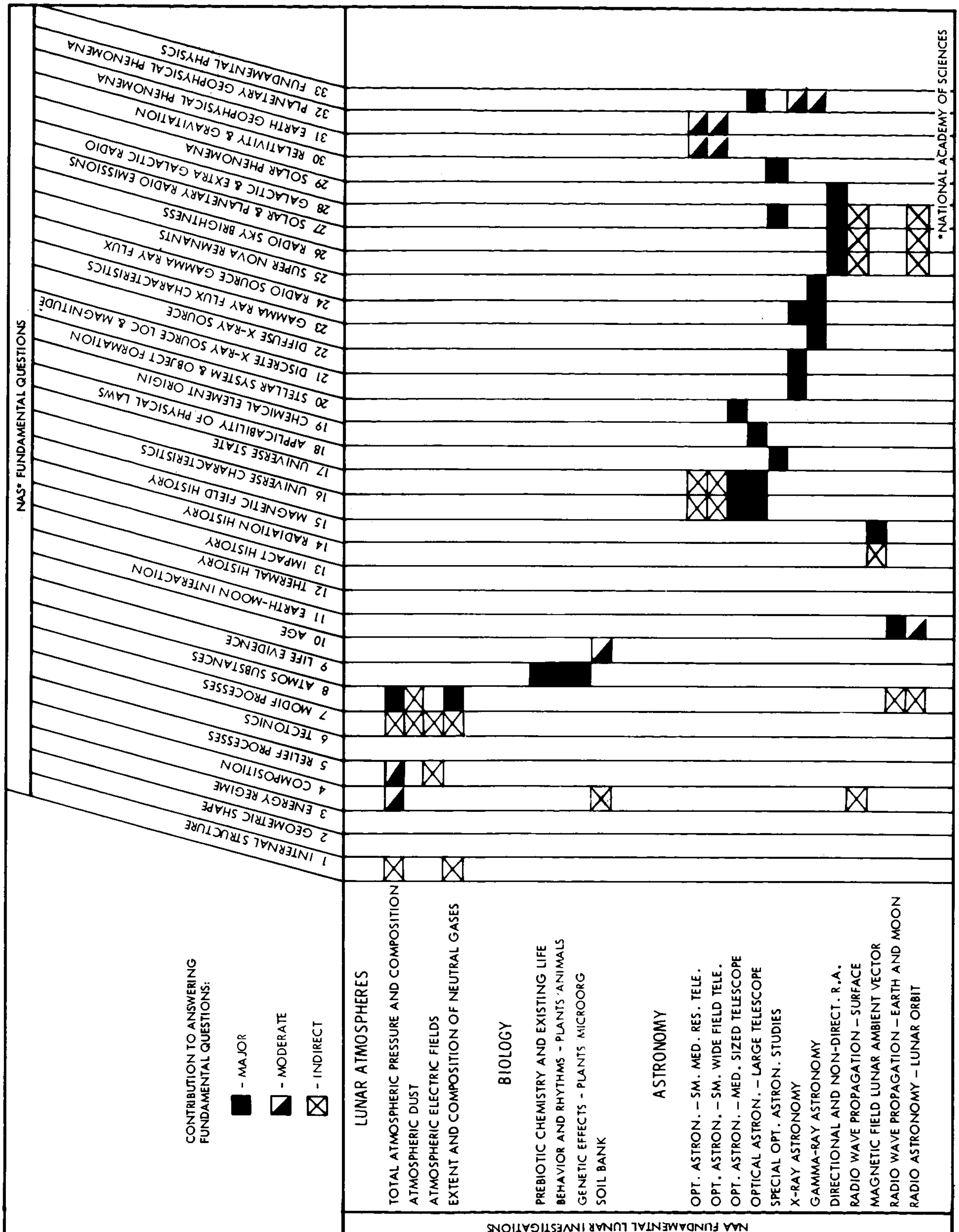

Figure 1d. Correlation of Fundamental Investigations With Fundamental Questions Raised by Space Science Board, National Academy of Sciences

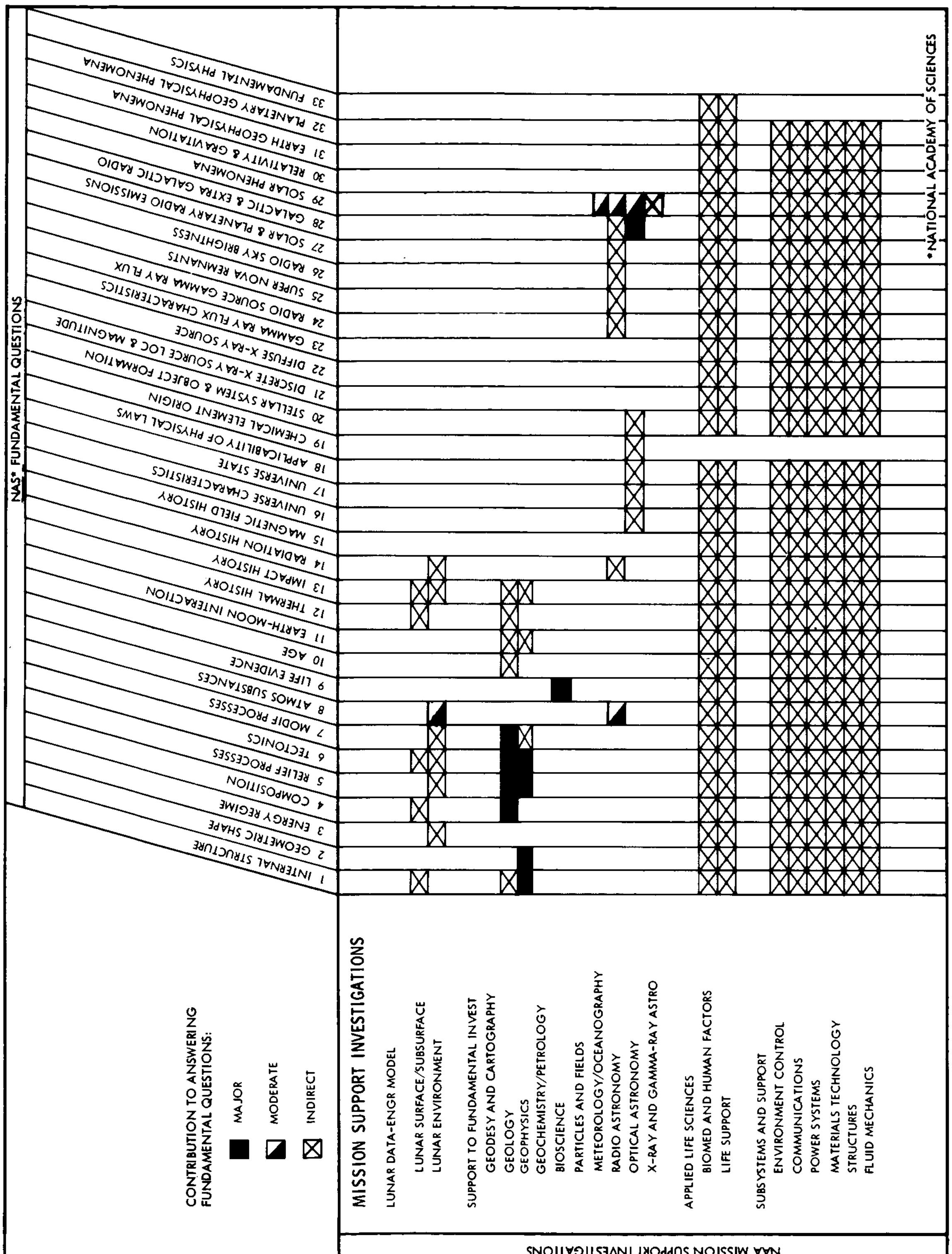

Figure 1e. Correlation of Mission Support Investigations With Fundamental Questions Raised by Space Science Board National Academy of Sciences

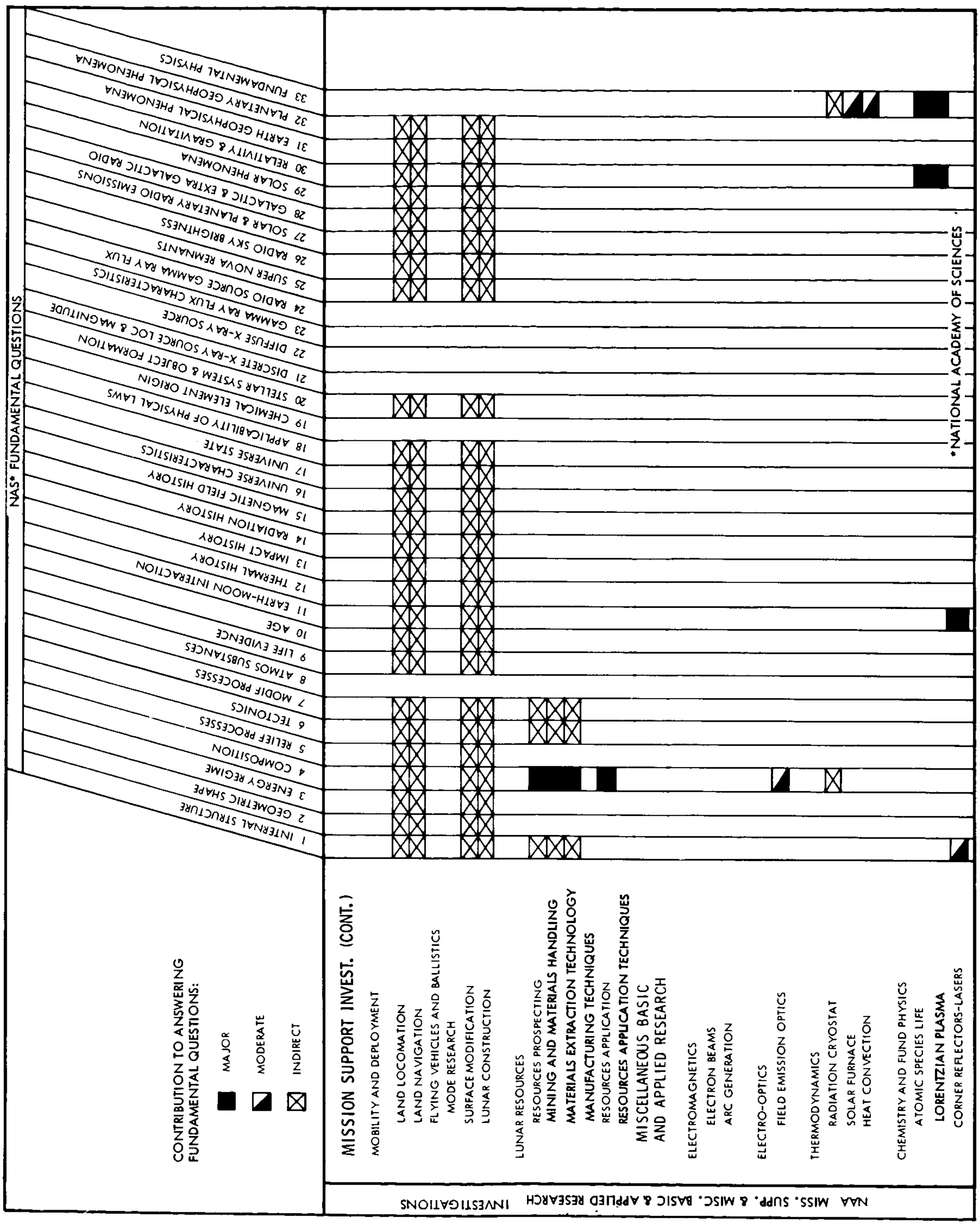

Figure 1f. Correlation of Mission Support and Miscellaneous Basic and Applied Research Investigations With Fundamental Questions Raised by Space Science Board, National Academy of Sciences

The experiment compilation is believed to (1) provide reasonable scientific coverage, (2) reflect the content of the source documents, (3) provide descriptive and support requirements data, and (4) provide output formats suitable for management and scientific review, and for systems and mission analysis.

5.3 MISSION SUPPORT INVESTIGATIONS AND MISCELLANEOUS BASIC AND APPLIED RESEARCH

Specific objectives of the Mission Support Investigations are as follows:

1. Obtain lunar properties and environment data necessary to develop an experiment-based, lunar engineering model.

2. Define basic experiment/environment and subsystems/environment interface phenomena with the lunar surface, subsurface, and near-surface environment and assess methods for adjusting to or improving the interactions.

3. Obtain correlative information with which to calibrate fundamental experiment equipment and data.

4. Assess the effectiveness of Earth-developed techniques that give confidence to the validity of information gained from fundamental investigations.

5. Test experiment performance and operations techniques on a reduced scale at an early time to provide developmental data.

6. Support scientific mission planning by providing criteria that contribute to the sequencing of investigations and phasing of missions.

7. Ensure crew well-being and safety, improve astronaut effectiveness, and aid his adaptation to the lunar environment.

8. Advance biological sciences technology in the lunar environment for application to ecology, and assess possible genetic effects of lunar missions.

9. Acquire test data on the behavior of Earth materials and equipment components in the unique lunar thermal-vacuum environment.

10. Advance capability and safety of vehicle locomotion on and above the lunar surface.

11. Advance capabilities to perform repair and deployment operations on the lunar surface.

12. Assess and demonstrate the feasibility of utilizing lunar resources.

The overall objective of the Miscellaneous Basic and Applied Research area is to take advantage of the unique properties and environment of the Moon and of lunar laboratory and base facilities to perform investigations for advancing scientific and technical knowledge and capabilities that may not necessarily be lunar-oriented. Lunar environmental conditions advantageous to the performance of research include: (1) an extensive deep vacuum, (2) a low gravity environment, (3) focusable, unfiltered thermal energy from the Sun, (4) the availability of deep space as a heat sink, (5) foundation stability for emplacement and alignment, and (6) potentially usable materials.

These objectives are reflected in the content of the 105 experiments and investigations formulated in the Mission Support and Miscellaneous Basic and Applied Research areas. Table 2 presents the organization of the Mission Support and Miscellaneous Basic and Applied Research areas into specialties and investigations. In the Mission Support area, the investigations (second-level titles) are presented in functional specialty groupings (first-level headings). A general correlation can be made between investigations and the preceding objectives. These experiments were not analyzed as comprehensively nor defined in as much detail as were the fundamental experiments.

The experiments, as incorporated in the data system, represent the major output of the Mission Support and Miscellaneous Basic and Applied Research activity. The complete experiment descriptions, including experiment key data and text descriptions, are presented in Volume 3 of the Detailed Technical Report.

Content and sequencing of these experiments were guided by reviews conducted primarily by the NASA Office of Advanced Research and Technology and by the U.S. Army, Office of the Chief of Engineers, and integrated by North American Aviation. Consideration of the importance and sequencing criteria assigned by these two organizations, and relation to fundamental experiment support requirements indicated a need for performance of a majority of the support investigations during early exploration phases. Miscellaneous Basic and Applied Research Investigations were found to be generally consistent with support capabilities of later exploration phases.

The results of this study support the conclusion that the Mission Support and Basic and Applied Research investigations, in conjunction with the Fundamental Investigations, enhance the value of the total mission program. A balanced program not only extends the capability and, therefore, value of lunar missions, but offers advancements in science and technology for exploration of the planets, moons of other planets, and for application to Earth needs as well.

5.4 EXPERIMENT DATA MANAGEMENT SYSTEM

The experiment data management system developed during this study provides for organization, entry, storage and retrieval, updating, and handling (sorting, compiling, etc.) of experiment and associated equipment and support data.

Table 2. Mission Support Investigation and Miscellaneous Basic and Applied Research Summary

DISCIPLINE AREA 8 - MISSION SUPPORT INVESTIGATIONS	No. of Experiments Compiled	
Augmentation of Lunar Data for Engineering Model		19
Lunar surface/subsurface engineering properties	10	
Lunar environment characteristics	9	
Direct Support To Fundamental Investigations		16
Support to geodesy and cartography	0	
Support to geology	5	
Support to geophysics	4	
Support to geochemistry/petrology	1	
Support to bioscience	1	
Support to particles and fields	0	
Support to meteorology/oceanography	0	
Support to radio astronomy	3	
Support to optical astronomy	2	
Support to X-ray and gamma-ray astronomy	0	
Applied Life Sciences Investigations		18
Applied biomedical and human factors investigations	8	
Life support applied research	10	
Basic Subsystems and Support Investigations		27
Environmental control applied research	1	
Lunar communications applied research	6	
Power systems applied research	3	
Materials technology support	12	
Lunar structures research	2	
Fluid mechanics research	3	
Mobility and Deployment Support Investigations		7
Land locomotion research	2	
Land navigation research	2	
Lunar flying vehicle and ballistic mode research	0	
Surface modification technology	2	
Lunar construction technology	1	
Resources Utilization Feasibility		9
Lunar resources prospecting and analysis	6	
Mining and materials handling technology	1	
Materials extraction and processing technology	1	
Manufacturing techniques	0	
Resources application techniques	1	
Total:		96
DISCIPLINE AREA 9 - MISCELLANEOUS BASIC AND APPLIED RESEARCH		
Electromagnetics	2	
Electro-optics	1	
Thermodynamics	3	
Chemistry	1	
Fundamental Physics	2	
Total:		9

The objectives of the data management system are to (1) provide a logical organization and extensive capacity for compilation of experiment support data, (2) provide lunar mission and system analysts with directly useable, programmed data, defining mission support requirements.

The data management system utilizes text and numerical data relating to each scientific experiment in a format suitable for processing and sorting of the data on a digital computer system. Since the program resembles business-type computer operations, a business-type computer language (COBOL) and an IBM 7010 computer were selected. Details of some of the procedures and an illustration of the computer master report are shown in Volumes 4, 5, and 6 (Appendixes A, B, and C) of the Detailed Technical Report. These appendixes and the decks of punched IBM cards represent, insofar as the system is concerned, the major output of this task and the major output of this study in unabridged form.

Compaction of data descriptions for each experiment package is obtained by using coded entries for significant common descriptors. The codes provide description of experiments and experiment support requirements in terms of functional constraints, operations, personnel, measurement parameters, equipment, and selected subsystems support.

An 11-digit number is incorporated to facilitate data sorting and identification of the experiments. The first three digits define the card type and card number (for multiple cards that must be sorted and printed in sequence). The remaining eight digits form the experiment reference code described in Volume 3 of the Detailed Technical Report. The data are organized so that either complete experiment descriptions or selected outputs can be retrieved at the discretion of the user. Seven types of data cards are used, as follows:

The Type-0 card contains a written summary of an experiment. This card presents the objective of the experiment, the phenomena to be measured, the equipment, and the parametric range of measurement. Unique requirements or relationships that cannot be tabulated are also provided.

The Type-1 card contains an experiment summary produced by the computer from information stored in the remaining data cards.

The Type-2 card provides major information relative to experiment operations and mission support requirements.

The Type-3 card provides detailed estimates of astronaut man-hours required to set up, operate, analyze, and tear down the instrumentation or equipment necessary to support an experiment. The man-hour estimates are differentiated for shirtsleeve and spacesuit conditions while the astronaut is operating from a traverse vehicle or from a lunar base. All man-hours are estimated in terms of normal Earth environment (shirtsleeve, 1 "g" operation); a "K" factor must be used to convert these times to actual lunar operation times.

The Type-4 card is used to define the equipment requirements directly related to an experiment. This card includes a six-digit numerical code to facilitate identification of commonality and time sharing of equipment.

The Type-5 card contains a written description of the equipment.

The Type-6 card presents more detailed information concerning telemetry requirements. This card is typical of a series of cards that could be utilized to expand the experiment data management system to provide more detailed requirements for other subsystems.

Incorporation of the information on the standard punched cards of a computer system provides the capability of sorting the experiments in a variety of ways and of selectively extracting information from a large mass of experiment data.

Three general computer programs were generated for processing the data cards into the desired computer system output. The output from these programs consists of the master list of experiments, summary card listings, equipment listings, and other special listings. In addition to the programs directly utilized in this study, auxiliary programs can be written to search, select, and compile data in a variety of ways.

A procedure for revising or updating experiment data is another feature of the data management system. This feature allows changes of data on the computer program master tape without the necessity of rerunning the entire punched card input file. The updating feature allows additions of complete experiments by selection of a new experiment identification number with a check of the up-to-date run or experiment title run to avoid duplication of numbers.

The most significant result of the computer data retrieval program is the establishment of a flexible and expandable information storage and retrieval system that can be used as a management tool for use in lunar-exploration-mission and mission-support planning. This system is dynamic in nature; it has the ability to grow and change and, thereby, adapt to future requirements.

5.5 SYSTEMS AND SUBSYSTEMS

Analysis of requirements and concepts was performed for selected major systems and subsystems to assess implications of the scientific mission requirements to systems support. Specific areas investigated were astronaut suited capabilities, local and extended surface mobility, and two typical major scientific fixed-site facilities, namely, a long-wave radio telescope and a 100-inch-telescope astronomical observatory.

5.5.1 Astronaut Lunar Capabilities

A major portion of astronaut energy expenditure in lunar surface operations can be associated with two types of activities: those attendant with surface travel, and those attendant with the execution of work tasks. During these operations, the astronaut will be required to perform in environments that have been shown in References 5 and 6 to produce significant decrements in the productivity, capability, and efficiency of operators.

5.5.2 Surface Mobility Support

A distribution of specified requirements for mobility by general type for the compiled experiments indicated 145 experiments requiring walking mode support, 75 experiments requiring at least local mobility support, and 45 experiments requiring extended mobility support. For most effective performance of the experiments, the surface mobility requirements distribution would be 119 "Walk", 57 "LSSM*" and 89 "Rover" (Extended Mobility).

Based on the astronaut suited capabilities, experiment support requirements and analytical comparisons, general requirements for local mobility support were defined. This study indicates that, among other advantages, local mobility support:

1. Substantially reduces the time required for movement on the lunar surface, whether the distance traveled is a few meters or kilometers.

2. Reduces astronaut fatigue by facilitating seated low-energy operations.

3. Extends the duration limits for astronaut surface operations by reducing metabolic costs and supplying backup life support.

4. Provides advantages beyond those related to personnel transport such as equipment transport, convenience of local power supply, etc.

It is recommended that serious consideration be given to the incorporation of tiltable seats in the forward portion of the LSSM. These tiltable seats should permit forward rotation of the astronauts to positions that are essentially normal to the tasks to be accomplished. In the vertical position, the astronaut's feet should be proximal to the lunar surface. The restraints normally supplied for locomotive accelerations may have to be redesigned to meet the bracing/restraint needs for efficient work task performance.

The study also indicates that extended surface mobility support capabilities are required to:

1. Increase exploration range to a regional scale

2. Extend terrain negotiability to permit travel to areas of major geological significance

3. Extend the duration capability for manned traverses consistent with distance and with extended traverse site operations

*LSSM - Local Scientific Survey Module — A short-range (action radius 8 to 10 km, maximum range of single traverse 25 km,) open cabin surface vehicle, carrying 1 or 2 astronauts and containing neither environmental control nor life support system. Portable backpacks are the sole provision for life support with this mobility.

4. Provide investigation and experiment support functions, including onboard analytical facilities

5. Provide a basic mobile operations support capability, which, through specialized modular additions, makes possible the deployment and installation of major scientific facilities.

5.5.3 Long-Wave Radio Telescope

To assess the feasibility of implementing major radio astronomy investigations on the lunar surface, particularly from weight, packaging, and deployment standpoints, a preliminary design concept, utilizing a Mills-Cross configuration, was developed for a long-wave radio telescope for possible application to a lunar radio astronomy observatory. Operation in the long wave lengths beyond those receivable on Earth is desired to complement Earth-based radio astronomy.

The nominal design frequency is 1 megahertz, corresponding to a wave length of 300 meters. The frequency range of 0.3 to 1 megahertz is considered, with possible extension to 100 megahertz. To provide a 1-degree resolution capability at 1 megahertz requires an antenna baseline of 18 kilometers. The north-south and east-west arrays shown in Figure 2 each contain 48 half-wave dipoles per array cut for the center frequency of megahertz. Each dipole is 150 meters long.

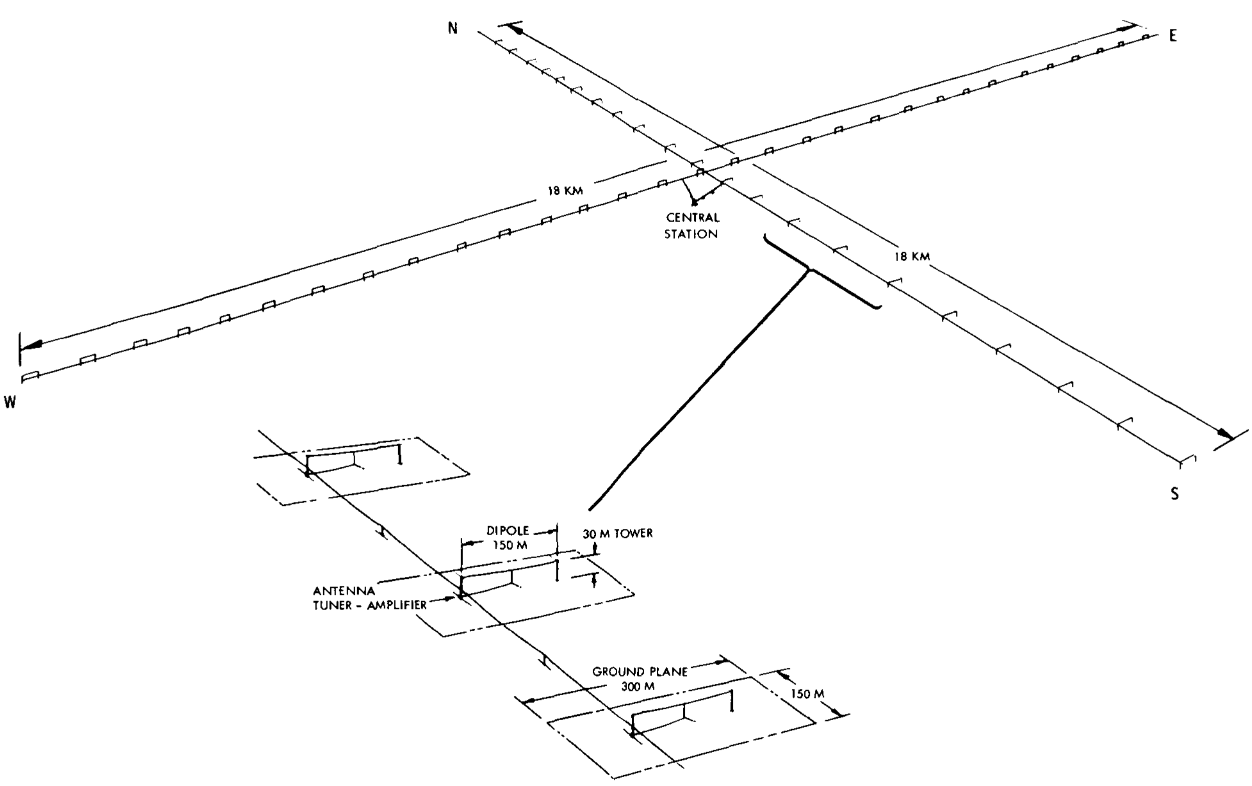

Figure 2. Lunar Long-Wave Radio Telescope Antenna Arrays for One Megahertz Frequency

The initial weight estimate for the complete interferometer system is 27,500 pounds or 12,500 kilograms. The 30-meter antenna towers are of telescoped design, and overall packaging is dense. Deployment would be performed using a large roving vehicle equipped with back-hoe and light construction support modules, assisted by an LSSM operating as a surveying and support vehicle.

5.5.4 100-Inch Telescope Concept

As a part of the major scientific equipment definition activities, a concept of a 100-inch horizontal telescope developed under a previous contract (Reference 3) was briefly reviewed. The review was directed primarily toward providing performance, packaging and deployment, and support data.

The optical concept of the 100-inch horizontal telescope was suggested originally by Dr. G.H. Herbig of the Lick Observatory. The primary objective was to take advantage of unique features of lunar basing to maximize telescope performance so that major scientific returns could be realized. To achieve this objective, the optics would have to be diffraction-limited for effective operation in the 1000 to 1500Å region. An aperture of not less than 100 inches was desired for which the theoretical resolution is about 0.01 arc second.

The original concept shown in Figure 3 includes a 200-inch aperture optical flat siderostat in a protecting dome, a 100-inch primary aperture and a 12.5-inch secondary mirror. The 100-inch and 12.5-inch mirrors are off-axis portions of 240-inch and 30-inch mirrors, respectively, mounted so that there is no obstruction of the primary mirror by the secondary mirror.

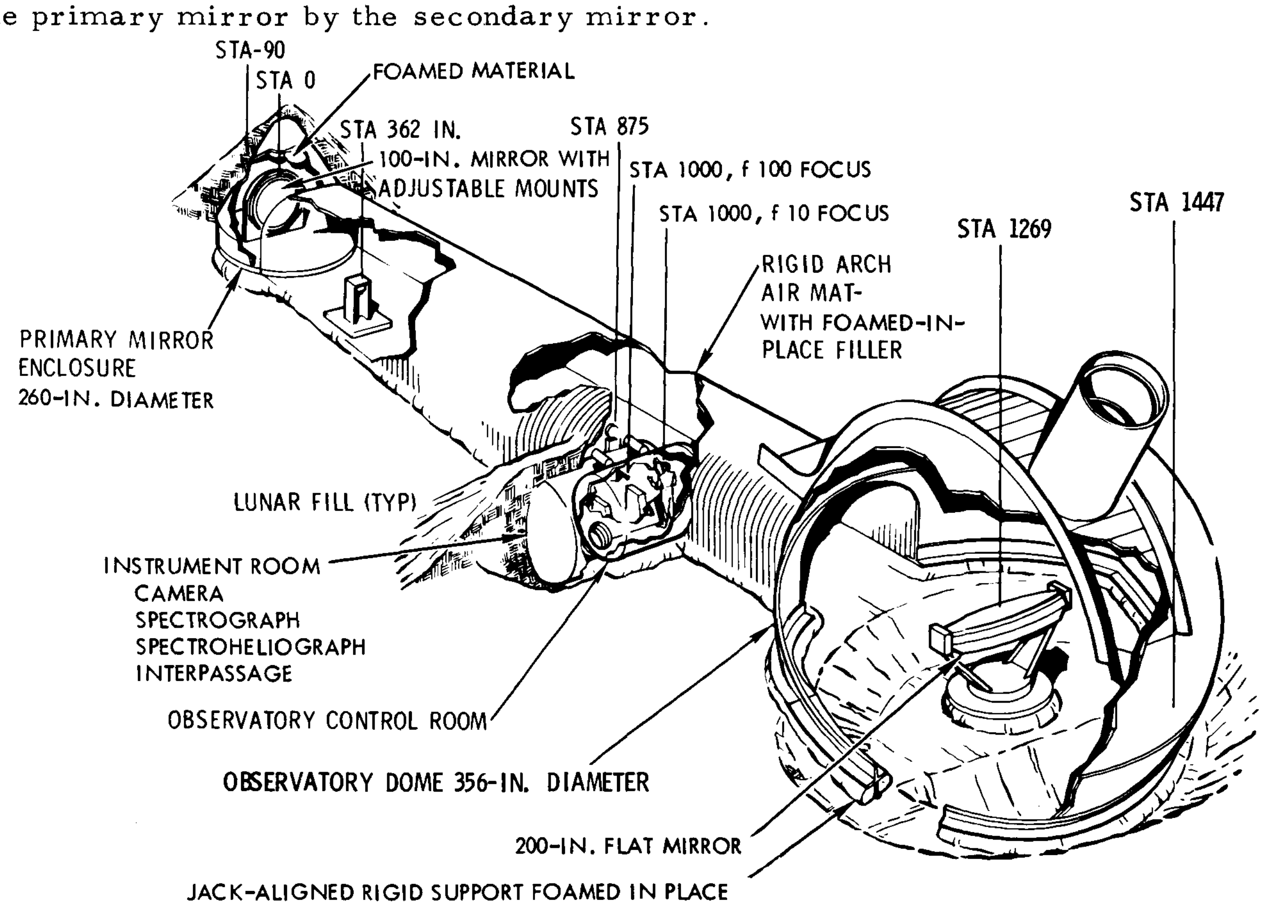

Figure 3. 100-Inch Telescope Concept (Modified From Reference 3)

In order to minimize packaging and deployment requirements, an analysis was made which resulted in size reduction of the large movable dome and shortening of the tunnel, with a corresponding decrease in payload weight. The dome was reduced to 356-inches in diameter allowing packaging in a 396-inch OD payload concept. Also, the siderostat and dome were moved toward the primary, displacing some 28 feet of light tunnel. Overall length is 37 meters (128 feet) and delivered weight is 18,000 kilograms (39,500 pounds). Packaging and deployment studies have shown that the telescope components can be delivered in two payloads of 240-inch ID, or in a single advanced payload of 356-inch ID.

These studies indicate that from an operational standpoint both the large radio and the optical astronomy facilities are feasible during the intermediate phases of extended lunar exploration.

5.6 EXPERIMENT SEQUENCING

The experiments were ordered intc Discipline Sequences, Mission Support Sequences, Exploration Phase Sequences, and Composite Sequences. Such sequencing allows identification of phases of lunar exploration and evolutionary programs and experiments within the capabilities of each phase, thereby providing tools for mission planning, equipment planning, and evaluation of lunar exploration systems based on scientific experiment requirements. These sequences are presented in Volume 4, Appendix A of the Detailed Technical Report.

The Discipline Sequences order the experiments in such a way as to achieve a logical progress of scientific knowledge and achievement within each discipline, and form a basis for the formulation of the other sequences.

The Mission Support Sequences, ordered by ascending mission support requirements such as mass, energy, and man-hours have been developed not only as an aid to the mission planner but as a basis for further sequence development. These sequences can be used to determine various combinations of mass to make up a payload, various energy combinations that are within the capability of a given energy source, and groupings of experiments that will be within a specified stay time on the lunar surface. In addition, they can be used to investigate the continuity of mission support parameters and to determine exploration phasing criteria.

The Exploration Phase Sequences separated the experiments of each discipline area into successive operational phases of lunar exploration. The basic criterion for determining an exploration phase was that experiments will be performed at the earliest phase at which the capability exists to perform them. Within any phase, ordering of experiments was according to the discipline sequences which were iterated to be compatible with the mission-support requirements analysis. Five exploration phases were identified, as shown in Table 3. Phase A is generally consistent with Apollo initial landings. Phase B is generally consistent with the present concept of the Apollo Applications Program and may be considered as early lunar exploration. Phase C might represent a transition to extended exploration, while Phases D and E definitely represent extended lunar exploration. The final totals of experiments per phase are 28 for Phase A, 145 for Phase B, 69 for Phase C, 50 for Phase D, and 14 for Phase E. The 30 orbital experiments and 4 correlative experiments which were compiled in this study and do not require lunar surface support were not incorporated with the phasing scheme. As a rule, these phases are not evolved from sudden discontinuities in data but, rather, from a smooth growth in requirements. The minimum vehicle requirements of each phase were estimated.

Composite Sequences evolved from the exploration-phase sequencing. For each identified exploration phase, individual experiments or groups of experiments were arranged into activities to be performed: (a) from lunar orbit, (b) on a traverse, (c) in a lunar base, and (d) either on a traverse or in a lunar base. Within each of these major groupings, the corresponding experiments were organized across scientific disciplines according to criteria imposed by 18 "key experiment items or operations." Examples of these "key" items or operations are: "Map and Survey," "Emplace and Monitor," "Drilling," "Sampling," "Telescope," and "Engineering Operational Feasibility."

The sequences evolved in this section contribute basic data for reference in planning lunar systems, developing scientific equipment, training astronauts, and coordinating efforts of the principal investigators.

Table 3. Mission-Support-Requirement Characteristics of Lunar Exploration Phases

Phase	Approximate Lunar Stay Time (days)	Maximum Energy Per Experiment (kilowatt-hours)	Maximum Mass Per Experiment (kilograms)	Average Man-Hours Per Experiment	Characteristic Mobility Mode	Remarks
A	3	0.6	20	5	Walking	Apollo
B	Less than 30	8	150	20	Short-range roving vehicle (LSSM-type)	Consistent with Apollo Application Program System Capability
C	90	50	500	120	Long-range roving vehicle	Extended exploration
D	180	200	4000	210		
E	More than 180	More than 200	More than 4000	640		

5.7 EARTH RESOURCE REQUIREMENTS

This task was restricted in scope to the support requirements necessary to analyze returned data. Primary requirements are for scientists, technicians, and laboratories. The conduct of this analysis was made in accordance with the Exploration Phase sequences previously discussed and required several assumptions concerning rate of execution of lunar exploration, time required to analyze returned data, etc., as described in the Detailed Technical Report, Volume 3.

Sensitivity analysis indicated that the requirement for scientists was most sensitive to the experiments and their returned data and most critical to scientific objective accomplishment. A deficit of approximately several thousand man-years of scientific work is forecast to be accrued by the end of Phase C. The short training requirement of technicians will allow development of a sufficient number of these personnel with minimum lead time and cost. Engineer availability is expected to be sufficient to support the requirements associated with scientific experimentation. Laboratory requirements estimates show a need for over seven million square feet of new laboratory space by the end of Phase D to support extended lunar exploration.

5.8 EXPLORATION PROGRAM FACTORS

The review of exploration program factors considered briefly the influence that the Apollo Applications Program, including lunar orbital experiments, can have on later mission phases, the relation of the lunar exploration program to planetary exploration, and contingencies which could substantially alter lunar exploration experiments or their sequencing.

Consideration of the Apollo Applications Program in relation to the scientific and mission support experiments which are candidates for performance in early exploration indicated a severely limiting man-hours constraint. This problem is compounded by the potential increase in man-hours for suited versus shirtsleeve operations. The relation of early to extended exploration was considered primarily in the context of the exploration phase sequencing.

Examination of lunar scientific and mission support experiments and investigations compiled in this study indicates that experiment objectives, experiment techniques, and equipment developed for and proven in extended lunar exploration will provide major advantages and support to planetary exploration. Thus, it appears that the lunar exploration program should be considered not only as a means of achieving intrinsic objectives but as a vital step in an evolutionary long-range space exploration program.

Planning and preparation for the accomplishment of lunar surface scientific objectives includes many long-lead-time activities such as experiment design and equipment development. Therefore, an examination was made concerning the handling of the effects of contingencies by the data management system. These effects would include changes in proposed experiments, experiment sequencing, experiment emphasis, or changes in lunar systems capability as improvement occurs in our basic understanding of the Moon.

6.0 STUDY LIMITATIONS

The scope of the study dictated that data-handling procedures be considered for 300 to 400 experiments. Full advantage could not be taken of all the individual experiments suggested or implied in the NASA 1965 Summer Conference on Lunar Exploration and Science. This conference was concerned primarily with early lunar exploration oriented toward foreseen early lunar exploration capabilities, with secondary consideration for extended lunar exploration in most cases. Many of the experiments suggested or implied in this conference which were closely related were necessarily combined to keep the total number of experiments, including extended lunar exploration, to a manageable figure.

The Mission Support and Miscellaneous Basic and Applied Research areas were constrained largely by budgetary considerations. Consequently, they provide only a partial spectrum of typical experiments that have not been carried to the same detail of analysis as the fundamental experiments.

Man-hour requirements for experiments are not sufficiently backed up by detailed operations analysis. This effort will require more detailed time and motion analysis for each experiment. The man-hours problem is augmented by increases in time required for space-suited operations versus Earth shirt-sleeve conditions. Experimental data concerning walking at 1/6 g in suited conditions are neither conclusive nor consistent, and the time factors suggested are subject to change.

Detailed definition of telemetry requirements was added to the experiment data management system late in the study. Coverage of the telemetry requirements is, therefore, preliminary in nature.

7.0 IMPLICATIONS FOR RESEARCH

A considerable amount of equipment required in support of lunar exploration has not been developed. Consequently, the need for major research and development in this area is implied.

Remote-sensing instruments and techniques such as multiband photographic techniques, vidicons, spectrometers, and radiometers which are being developed for orbital and unmanned space probe programs should be applicable to lunar exploration with little modification.

The most critical need for research appears to be in the area of human factors, with regard to man's operational capabilities in a lunar suit in the lunar environment. While this research is more of an applied nature, it will be very important to the eventual accomplishment of the fundamental investigations. Specific suit development improvements in the joints to reduce metabolic costs of movements, improvements in the gloves, and use of prosthetic devices are important aspects of this research.

Progress in drilling techniques is being made; however, this progress should be accelerated with the increased amount of data now being obtained concerning the lunar surface. Seismic experiments are most important in determining deep lunar subsurface characteristics, and drilling capability is the key to obtaining interpretive data as well as direct information concerning shallow subsurface characteristics.

Activities supported by NASA, such as the research being performed with the sounding rocket program and the Orbiting Astronomical Observatories, are contributing background and related technology for space-based and later lunar-based astronomy. The development and operation of a large orbiting telescope with manned operation will supply valuable design, development, and operating experience also applicable to lunar-based astronomy. Since the Moon is expected to provide a very stable platform, additional effort should be made to develop large diffraction-limited optics (100-inch) to take full advantage of the unique lunar environment. Basic research in the development of detectors is required to realize lunar astronomy objectives. This research and parallel research in radio astronomy are essential requirements to the support of extended lunar exploration.

8.0 SUGGESTED ADDITIONAL EFFORT

To keep the total number of Fundamental Experiments consistent with the level of effort of this study, broader experiment definitions were frequently utilized, resulting in a total of 235 Fundamental Experiments. Future effort should be applied to breaking the experiments into smaller units of discrete activity and providing more detail for definition of support requirements. The experiment data management system has more than ample capacity to incorporate this extension.

Specific support requirements should be defined in more detail. First priority should be given to the participation of man in the experiments, particularly when his participation involves lunar-suited operations. This consideration includes mobility and the integration of man, the vehicle (especially the short-range "open-cabin" type vehicle), and the experiments. Emphasis should be placed on automation and remote control operations in order to take maximum advantage of man's capabilities to observe, monitor, control, and reprogram.

The present lunar suit development program should be accelerated and additional basic research should be performed to better determine man's capabilities while operating in a lunar suit in the lunar environment. The program should be directed toward acquisition of data descriptive and predictive of the capabilities and requirements of astronauts in performing tasks believed to be representative of mission activities while wearing spacesuits in the reduced gravity environment. It is recommended that the experiment data management system be extended to provide more detailed information for lunar suit operations, considering the lunar-suited astronaut as a discrete subsystem. More detailed requirements for the environmental control and life support subsystem are closely related to the requirements previously described. These recommendations can be accommodated by the addition of two IBM cards to the present data management system.

The Mission Support and Miscellaneous Basic and Applied Research Experiments have been shown to be very important to the effective implementation of fundamental experiments and system support in addition to being of independent value. Additional effort to identify a more complete spectrum of experiments falling in these categories appears therefore to be justified. It is suggested that experiment definition be carried to the same depth as the fundamental experiments. This experiment definition will benefit lunar systems planning by providing a more complete picture of mission support requirements. Relation of the lunar mission support experiments to preceding Earth-based research will be rewarding in planning and assessing the supporting research program requirements.

Lunar Fundamental, Mission Support, and Miscellaneous Basic and Applied Research Experiments should be correlated and integrated with planetary exploration requirements. Potential benefits to both the planetary and lunar exploration program make this a priority effort. It is suggested that the data management system techniques be applied to orbital and planetary scientific mission support requirements.

9.0 REFERENCES

1. NASA 1965 Summer Conference on Lunar Exploration and Sciences, July 19 to 31, 1965, National Aeronautics and Space Administration, NASA SP-88 (July 1965).

2. Space Research—Directions for the Future, National Academy of Science, National Research Council (January 1966).

3. A Study of Scientific Mission Support of a Lunar Exploration System for Apollo, NASA Contract NASW-1047, NAA S&ID, SID 65-289 (16 June 1965).

4. Mission Modes and Systems Analysis for Lunar Exploration, NASA Contract NAS8-20262 with Lockheed Missiles and Space Company (Interim Reports).

5. Streimer, I., D.P.W. Turner, G.A. Tardiff, and T.L. Stephens, "An Investigation of the Effects of Pressure Suit Wearing on Work Output Characteristics," Aerospace Medicine, Vol. 35, No. 8, (Aug. 1964) pp. 747-751

6. Adams, C.R. and G. Hanff, "Some Human Factor Considerations for Orbital Maintenance and Materials." 35th Annual Scientific Meeting, Aerospace Medicine Association (May 1964).